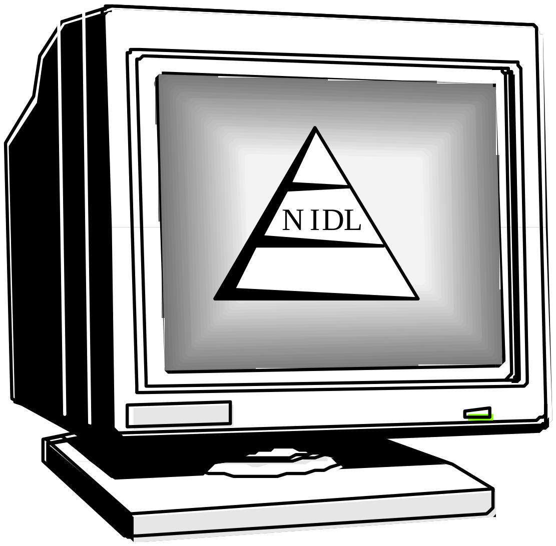

The Sony GDM F500R 21-inch, color, perfectly flat face, 0.22 mm aperture grill monitor (19.8" viewable area; selling price $1800) has good image quality and features that make it an excellent candidate display device for NIMA Imagery Exploitation Capability workstations. Based on our evaluation, NIDL certifies the Sony F500R color monitor as being suitable for IEC workstations. NIDL rates this color monitor as a “B-” in monoscopic mode and as “C” in stereographic mode. The monitor nearly meets all IEC requirements in the monoscopic mode; the exceptions are warm-up and linearity. The stereo extinction ratio of 13.3:1 measured with a NuVision panel and passive polarizing glasses is comparable to the best measured for a color monitor. The stereo refresh is 112 Hz, rather than 120 Hz required by the IEC specification, but is higher than for the 24 inch Sun monitor.

Evaluation of the Sony GDM F500R 4 x 3 Aspect Ratio, 21-Inch Diagonal Color, Flat Face, 0.22mm CRT Monitor

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NIDL IEC Monitor Certification Report

The Sony GDM F500R Color CRT Monitor

FINAL GRADES
Monoscopic Mode: B-
Stereoscopic Mode: C

A=Substantially exceeds IEC Requirements; B= Meets IEC Requirements; C=Nearly meets IEC Requirements; F=Fails to meet IEC Requirements in a substantial way

The Sony GDM F500R 21-inch, color, perfectly flat face, 0.22 mm aperture grill monitor (19.8" viewable area; the selling price is $1800) has good image quality and features that make it an excellent candidate display device for NIMA Imagery Exploitation Capability workstations. Based on our evaluation, NIDL certifies the Sony F500R color monitor as being suitable for IEC workstations. NIDL rates this color monitor as a “B-” in monoscopic mode and as “C” in stereographic mode. The monitor meets all critical IEC requirements in the monoscopic mode. The stereo extinction ratio of 13.3:1 measured with a NuVision panel and passive polarizing glasses is comparable to the best measured for a color monitor. However, the maximum refresh rate in stereo is 56 Hz per eye, not the 60 Hz per eye specified by the IEC specification, but is higher than the 46 Hz per eye for the 24 inch Sun. The refresh rate in stereo appears to be limited by the horizontal scan frequency of 121 kHz.

The Sony F500R is a versatile color monitor and is an OEM product of the well-regarded F Series displays. It features a Multiscan® FD Trinitron® CRT with a virtually-flat screen, tight 0.22mm aperture grille, and HiDensity™ Electron Gun with Enhanced Elliptical Correction System™ technology and GeoLock Plus™ circuitry to automatically sense and neutralize electromagnetic fields that can cause image or color distortion. The reliability of the Sun 24 inch manufactured by Sony has been excellent and it is expected to be the same for the Sony GDM F500R monitor.

The 4:3 aspect ratio and the 21 inch diagonal give the analyst a large working area surpassed only by 24-inch wide-screen monitors. The monitor meets all critical IEC requirements in the monoscopic mode. The warm-up time and scan nonlinearity of 1.3% exceed the maxima allowed by the IEC specification. In the stereo mode, the 56 Hz (per eye) refresh rate is less than required in the IEC specification. The stereo extinction ratio of 13.3:1 measured with a NuVision panel and passive polarizing glasses is comparable to the best measured for a color monitor. The value is somewhat less that the 15:1 ratio in the IEC requirement. This value of 15:1 had been measured using wireless StereoGraphics CrystalEyes shutter glasses that may give a somewhat higher extinction ratio than do the stereo NuVision panel or Zscreen and passive polarizing glasses that we used in our evaluation.

The manufacturer lists the maximum addressability for the Sony F500R as 1856 x 1392 pixels. However, the horizontal phosphor pitch of 0.22 mm limits the number of red, green and blue phosphor stripes that can be addressed to less than 1856 pixels in the horizontal direction. As

evaluated, NIDL's measurements for a viewable image size of 15.038 x 11.486 inches indicate a maximum of 1736 pixels in the horizontal direction based on the horizontal phosphor pitch.

The Sony F500R monitor is described on the website:
http://www.ita.sel.sony.com/products/displays/cad/gdmf500r.html.

Color monitors are more difficult to evaluate and their performance may not compare to monochrome monitors. Color monitors have three electron guns (R, G, and B) to focus and converge. They also have a perforated steel shadow mask that separates the colors on the screen and this adds complexity. Color lines formed on the phosphor screen may not be as narrow as for a monochrome, single electron gun-formed spot. The color monitor's light output may not be as high. The IEC monitor specifications for color monitors reflect this difference, and have lower luminance and stereo extinction ratio requirements than a monochrome monitor. In spite of these limitations, Imagery Analysts at a number of sites may do all their analyses on color monitors.

NIDL evaluated the Sun 24 inch color monitor, gave it an "A" for its performance, and recommended its use for imagery analysts. We based this recommendation on its measured performance, analysts' preference for the 24 inch diagonal, the 16:10 format with its greater area, and on its reliability. The Sony F500 monitor is a very good color monitor, but the 24 inch Sun monitor performs better in the following areas:

- Luminance, 5 to 28% higher for Sun 24 inch monitor compared to Sony F500R
- Uniformity, about the same for the Sun 24 inch and the Sony F500R
- Halation, 49% lower for Sony F500R
- Reflectance, about same for both monitors
- Contrast modulation, Zone A (Sun 24 inch up to 50% better than the Sony F500R)
- Contrast modulation, Zone B (Sun 24 inch up to 50% better than the Sony F500R)
- Linearity, 38% better for the Sun 24 inch
- Warm-up, Sun 24 inch about twice as fast as the Sony F500R
- Vertical refresh rate in stereo is better for the Sony F500, 112 Hz versus 92 Hz for the Sun 24 inch, so flicker should be less in stereo with the Sony GDM F500R
- Extinction ratio in stereo, about the same for Sony F500 compared to Sun 24 inch

In ambient lighting with 3 or 10 fc falling onto the face of the monitor, both perform about the same.

The dimensions for the Sony F500 are: 19.8 inch Wide x 20 inch High x 18.7 inch Deep x 71 pounds. The 24 inch Sony is 22.8 inch wide x 19.8 inch high x 21.6 inch deep x 90 pounds.

Thus price, $2500 for the 24 inch Sun versus about $1800 for the 21 inch Sony GDM F500R and depth of the monitor may be deciding factors in the choice of color monitor in addition to performance.

Evaluation Datasheet

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC			
Addressability	1024 x 1024 min.	1600 x 1200	pass
Dynamic Range	24.7dB	25.6 dB	pass
Luminance (Lmin)	0.1 fL min. ± 4%	0.10 fL	pass
Luminance (Lmax)	30 fL ± 4%	36.2 fL	pass
Uniformity (Lmax)	20% max.	12.3 %	pass
Halation	3.5% max.	1.92 %	pass
Color Temp	6500 to 9300 K	9380K	pass
Reflectance	Not specified	6.30%	
Bit Depth	8-bit± 5 counts	8-bit	pass
Step Response	No visible ringing	Clean	pass
Uniformity (Chromaticity)	0.010 delta u'v' max. ± 0.005 Δ u'v'	0.003 delta u'v'	pass
Pixel aspect ratio	Square H = V± 6%	Set to square 9.4 x 9.57 mils	pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	18.9 inches	pass
Cm, Zone A	25% min.	43%	pass
Cm, Zone B	20% min.	37%	pass
Pixel density	72 ppi min.	106 ppi	pass
Moiré, phosphor-to-pixel spacing	1.0 max	0.92	pass
Straightness	0.5% max ± 0.05 mm	0.12 %	pass
Linearity	1.0% max ± 0.05 mm	1.32 %	fail
Jitter	2 ± 2 mils max.	2.76 mils	pass
Swim, Drift	5 ± 2 mils max.	3.17 mils	pass
Warm-up time, Lmin to +/- 50%	30 mins. Max ± 0.5 minute	47 min.	fail
Warm-up time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	75 mins.	fail
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 72 Hz	pass
STEREOSCOPIC			
Addressability	1024 x 1024 min.	1024 x 1024	pass
Lmin	0.1 fL	0.1 fL	
Lmax	6 fL min ± 4%	7.49 fL	pass
Dynamic range	17.7 dB min	18.9 dB	pass
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 Δ u'v'	0.006	pass
Refresh rate	60 Hz per eye, min	56 Hz	fail
Extinction Ratio	15:1 min	13.3 : 1	fail
AMBIENT LIGHTING			
Dynamic Range 22 dB (158:1)	N/A	3 fc	
Dynamic Range 17.1 dB (51:1)	N/A	10 fc	

(I) denotes interlaced scanning
(n) denotes Nuvision LCD shutter panel

Section I INTRODUCTION

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users. The Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics, hosts the NIDL.

The present study evaluates a production unit of the Sony GDM F500R, color CRT high-resolution display monitor. This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

The IEC requirements, procedures and calibrations used in the measurements are detailed in the following:

- *NIDL Publication No. 0201099-091*, *Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC),* August 25, 1999.

Two companion documents that describe how the measurements are made are available from the NIDL and the Defense Technology Information Center at http://www.dtic.mil:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Draft Version 2.0. (ADA353605)*

- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

Other procedures are found in a recently approved standard available from the Video Electronics Standards Association (VESA) at http://www.vesa.org:

- *VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998.*
  Publication No. 0201099-091, Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC), August 25, 1999.

The IEC workstation provides the capability to display image and other geospatial data on either monochrome or color monitors, or a combination of both. Either of these monitors may be required to support stereoscopic viewing. Selection and configuration of these monitors will be made in accordance with mission needs for each site. NIMA users will select from monitors included on the NIMA-approved Certified Monitor List compiled by the NIDL. The color and monochrome, monoscopic and stereoscopic, monitor requirements are listed in the Evaluation Datasheet.

I.1 The Sony F500R Color CRT Monitor

Sony's Specifications

According to Sony, the specifications for the Sony F500R monitor are:

Price	$1899.99 estimated U.S. retail selling price. Actual retail price may vary.
CRT	21" FD Trinitron®, virtually-flat screen
Viewable Image Size	19.8"
Aperture Grille Pitch	0.22mm
Screen Treatment	Anti-Reflective Coating
Electron Gun	HiDensity™ Electron Gun with Enhanced Elliptical Correction System™ technology
Horizontal Scan Range	30-121kHz
Vertical Scan Range	48-160Hz
Maximum Resolution	2048 x 1536 @ 75Hz
Color Temperature Presets	5000 Kelvin, 6500 Kelvin, 9300 Kelvin, User-adjustable Settings (Bias/Gain Control), sRGB
Signal Inputs	Analog RGB, 0.7Vp-p, 75ohm (typical)
External Sync Signals	Separate/Composite 1-5Vp-p, polarity-free TTL, Sync on Green: 0.3Vp-p, negative
Input Connectors	15 pin mini D-sub and 5 BNC connectors
Power Requirements	90-264V AC; 50-60Hz
Power Management	International Energy Star, NUTEK and VESA DPMS Compliant, Operation: 145 watts (maximum), Suspend: 15 watts (maximum), Active Off: 1 watt (maximum), Power Off: <0 watt
Dimensions (WxHxD)	19.8" x 20.0" x 18.7"
Weight	70.5 lbs.
Operating Temperature	50°F-104°F (10°C-40°C)
Operating Humidity	10%-80% (Non-Condensing)
Regulation and Standard Compliance	Safety: UL 1950, CSA 22.2 No. 950, EN60950 (TUV, GS mark), Emission/EMI: FCC Class B, IC Class B, MPR II TUV (full compliance), TCO '99, X-ray: DHHS, DNHW, PTB, Ergonomics: ZH1/618, ISO9241-3, -7.-8, Designed for: Microsoft Windows® 2000, Windows® 98, Macintosh Compatible, Plug & Play: DDC-1, DDC-2B, DDC-2Bi, DMI Compliant, VESA: Generalized Timing Formula (GTF)
Front Panel Digital Controls	Power On/Off, Active Signal Correction (ASC™), Reset, Brightness, Contrast, Input Switching Button, On-Screen Display (OSD), Brightness/Contrast, H/V Size, H/V Centering, Zoom, Raster Rotation, Pincushion, Pin Balance, Keystone, Key Balance, Color Temperature, sRGB, H/V Convergence: Top/Bottom V Convergence, Landing Correction (4 Corners), Moiré Cancellation, Moiré Adjustment, Manual Degauss, H/V OSD Position, Image Restoration, Control Lock, Multi-Language Select (9 languages)
USB Compatible	Built-in, self-powered USB hub with one upstream and four downstream ports
Supplied Accessories	Tilt Base/Wide Angle Swivel (±90°) Stand, Video Signal Cable (15 pin mini D-sub), AC Power Cord, Macintosh Adapter, Windows 95/98 inf. Diskette, USB Cable
Limited Warranty	3 Years: Parts, Labor, and CRT

I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p 5.

All measurements will be made with the display commanded through a laboratory grade programmable test pattern generator. The system will be operated in at least a 24 bit mode (as opposed to a lesser or pseudo-color mode) for color and at least 8 bits for monochrome. As a first step, refresh rate should be measured and verified to be at least 72 Hz. The screen should then be commanded to full addressability and Lmin set to 0.1 fL. Lmax should be measured at screen center with color temperature between D65 and D93 allowable and any operator adjustment of gain allowable. If a value >35fL is not achieved (>30 fL for color), addressability should be lowered. For a nominal 1200 by 1600 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability, addressabilities of 1200 x 1600 and 1024 x 1024 can be evaluated if the desired Lmax is not achieved at full addressability.

I.3. Equipment

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

The procedures described in this report should be carried out in a darkened environment such that the stray luminance diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m^2 (1mfL).

Instruments used in these measurements included:

- Quantum Data 8701 400 MHz programmable test pattern signal generator
- Quantum Data 903 250 MHz programmable test pattern signal generator
- Photo Research SpectraScan PR-650 spectroradiometer
- Photo Research SpectraScan PR-704 spectroradiometer
- Minolta LS-100 Photometer
- Minolta CA-100 Colorimeter
- Graseby S370 Illuminance Meter
- Microvision Superspot 100 Display Characterization System which included OM-1 optic module (Two Dimensional photodiode linear array device, projected element size at screen set to 1.3 mils with photopic filter) and Spotseeker 4-Axis Positioner

Stereoscopic-mode measurements were made using the following commercially-available stereo products:

- Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Section II PHOTOMETRIC MEASUREMENTS

II.1. Dynamic range and Screen Reflectance

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.*

VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 199, Section 308-1.

Full screen white-to-black dynamic range measured in 1600 x 1200 format is 25.6 dB in a dark room. It decreases to less than 22 dB (the absolute threshold for IEC) in 3 fc diffuse ambient illumination.

Objective: Measure the photometric output (luminance vs. input command level) at Lmax and Lmin in both dark room and illuminated ambient conditions.

Equipment: Photometer, Integrating Hemisphere Light Source or equivalent

Procedure: Luminance at center of screen is measured for input counts of 0 and Max Count. Test targets are full screen (flat fields) where full screen is defined addressability. Set Lmin to 0.1 fL. For color monitors, set color temperature between D_{65} to D_{93}. Measure Lmax.

This procedure applies when intended ambient light level measured at the display is 2fc or less. For conditions of higher ambient light level, Lmin and Lmax should be measured at some nominal intended ambient light level (e.g., 18-20 fc for normal office lighting with no shielding). This requires use of a remote spot photometer following procedures outlined in reference 2, paragraph 308-2. This will at best be only an approximation since specular reflections will not be captured. A Lmin > 0.1 fL may be required to meet grayscale visibility requirements.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are simultaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in figure II.1-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by an integrating hemisphere simulated using a polystyrene icebox. Luminance is measured using a spot photometer with 1° measurement field and an illuminance sensor as depicted in Figure II.1-1. The measured values and calculated reflectances are given in Table II.1-1.

Data: Define dynamic range by: $DR=10\log(Lmax/Lmin)$

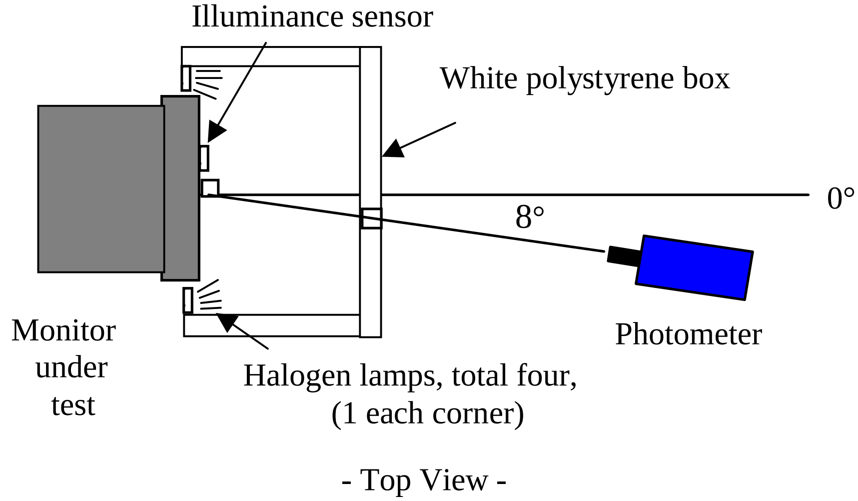


Figure II.1-1. Test setup according to VESA FPDM procedures for measuring total reflectance of screen.

Table II.1-1. Directed Hemispherical Reflectance of Faceplate

VESA ambient contrast illuminance source (polystyrene box)

Ambient Illuminance	20.8 fc
Reflected Luminance	1.3 fL
Faceplate Reflectance	6.3 %

Ambient dynamic ranges of full screen white-to-black given in Table II.1-2 were computed for various levels of diffuse ambient lighting using the measured value for DHR and the darkroom dynamic range measurements. Full screen white-to-black dynamic range decreases from 25.9 dB in a dark room to 22 dB (the absolute threshold for IEC) in 3 fc diffuse ambient illumination.

Table II.1-2.Dynamic Range in Dark and Illuminated Rooms

Effect of ambient lighting on dynamic range is calculated by multiplying the measured CRT faceplate reflectivity times the ambient illumination measured at the CRT in foot candles added to the minimum screen luminance, Lmin, where Lmin = 0.1 fL.

Ambient Illumination	**Dynamic Range**
0 fc (Dark Room)	25.6 dB
1 fc	23.5 dB
2 fc	22.1 dB
3 fc	21.0 dB
4 fc	20.2 dB
5 fc	19.5 dB
6 fc	18.9 dB
7 fc	18.3 dB
8 fc	17.9 dB
9 fc	17.4 dB
10 fc	17.1 dB

II.2. Maximum Luminance (Lmax)

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.2, p 6.*

The highest luminance for Lmax was 36.2 fL measured at screen center in 1600 x 1200 format.

Objective: Measure the maximum output display luminance.

Equipment: Photometer

Procedure: See dynamic range. Use the value of Lmax defined for the Dynamic Range measurement.

Data: The maximum output display luminance, Lmax, and associated CIE x, y chromaticity coordinates (CIE 1976) were measured using a hand-held colorimeter (Minolta CA-100). The correlated color temperature (CCT) computed from the measured CIE x, y chromaticity coordinates was within range specified by IEC (6500K and 9300K).

Table II.2-1. Maximum Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at screen center.

Format	CCT	CIE x	CIE y	Luminance
1600 x 1200	9380K	0.284	0.292	36.2 fL

II.3. Luminance (Lmax) and Color Uniformity

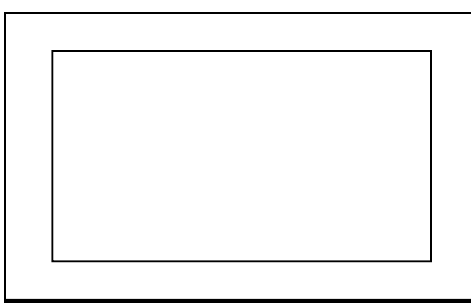
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

Maximum luminance (Lmax) varied by up to12.3 % across the screen. Chromaticity variations were less than 0.003 delta u'v' units.

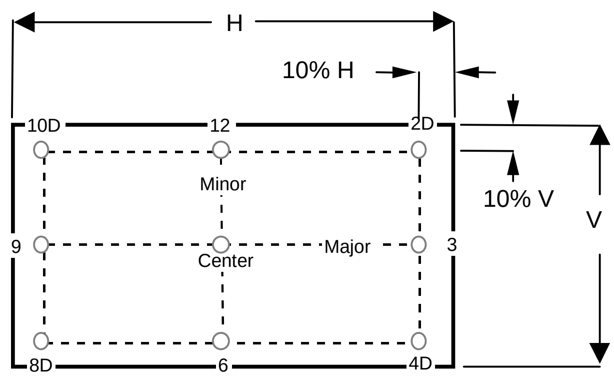
Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% Lmax only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

Equipment:
- Video generator
- Photometer
- Spectroradiometer or Colorimeter

Test Pattern: Full screen flat field with visible edges at L_{min} as shown in Figure II.3-1.



Full Screen Flat Field test pattern.
Figure II.3-1



Nine screen test locations.
Figure II.3-2

Procedure: Investigate the temporal variation of luminance and the white point as a function of intensity by displaying a full flat field shown in Figure II.3-1 for video input count levels corresponding L_{max}. Measure the luminance and C.I.E. color coordinates at center screen.

Investigate the temporal variation of luminance and the white point as a function of spatial position by repeating these measurements at each of the locations depicted in Figure II.3-2. Define color uniformity in terms of Δ u´v´.

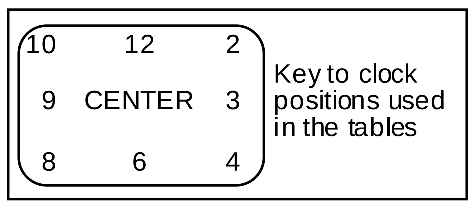
Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Table II.3-1.Spatial Uniformity of Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at nine screen positions.

1600 x 1200

POSITION	CCT	CIE x	CIE y	L, fL
center	9380	0.284	0.292	36.2
2	9425	0.284	0.291	38.6
3	9174	0.286	0.292	35.4
4	9132	0.287	0.291	34.9
6	9229	0.286	0.291	34.9
8	9146	0.286	0.293	38.7
9	9327	0.285	0.291	37.8
10	8920	0.288	0.294	39.2
12	9327	0.285	0.291	36.3



1600 x 1200

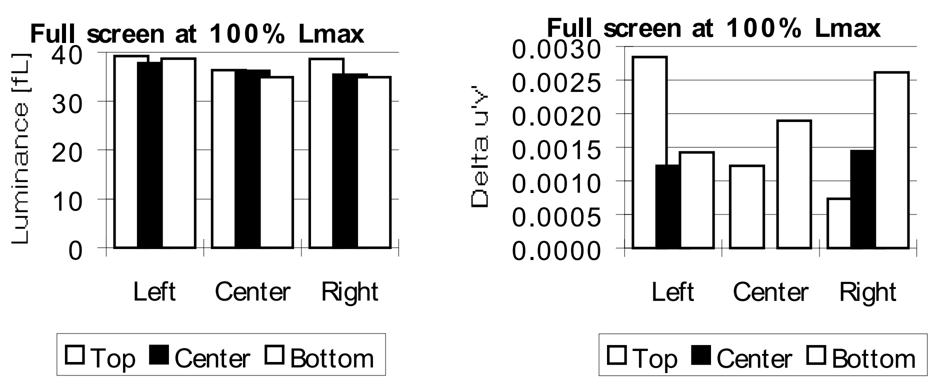


Fig.II.3-3. Spatial Uniformity of Luminance and Chromaticity. (Delta u'v' of 0.004 is just visible.)

II.4. Halation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 48.

Halation was 1.92% +/- 0.2% on a small black patch surrounded by a large full white area.

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. The mechanisms that give rise to halation, and its detailed non-monotonic dependence on the distance along the screen between the source of illumination and the region being measured have been described by E. B. Gindele and S.L. Shaffer. The measurements specified below determine the percentage of light that is piped into the dark areas as a function of the extent of the surrounding light areas.

Equipment:

- Photometer
- Video generator

Test Pattern:

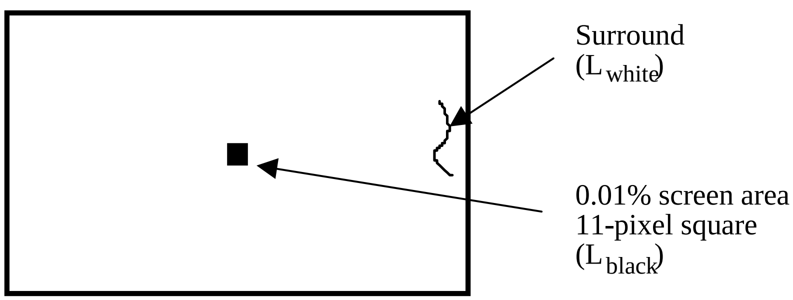


Figure II.4-1 *Test pattern for measuring halation.*

Procedure: Note: The halation measurements require changing the setting of the BRIGHTNESS control and will perturb the values of L_{max} and L_{min} that are established during the initial monitor set-up. The halation measurements should therefore be made either first, before the monitor setup, or last, after all other photometric measurements have been completed.

Determine halation by measuring the luminance of a small square displayed at L_{black} (essentially zero) and at L_{white} when surrounded by a much larger square displayed at L_{white} (approximately 75% L_{max}).

Establish L_{black} by setting the display to cutoff. To set the display to cut-off, display a flat field using video input count level zero, and use a photometer to monitor the luminance at center screen. Vary the BRIGHTNESS control until the CRT beam is visually cut off, and confirm that the corresponding luminance (L_{stray}) is essentially equal to zero. Fine tune the BRIGHTNESS control such that

CRT beam is just on the verge of being cut off. These measurements should be made with a photometer that is sensitive at low light levels (below L_{min} of the display). Make no further adjustments or changes to the BRIGHTNESS control or the photometer measurement field.

Next, decrease the video input level to display a measured full-screen luminance of 75% L_{max} measured at screen center. Record this luminance (L_{white}).

The test target used in the halation measurements is a black (L_{black}) square patch of width equal to 0.01% of the area of addressable screen, the interior square as shown in Figure II.4-1. The interior square patch is enclosed in a white (L_{white}) background encompassing the remaining area of the image. The exterior surround will be displayed at 75% L_{max} using the input count level for L_{white} as determined above. The interior square will be displayed at input digital count level zero.

Care must be taken during the luminance measurement to ensure that the photometer's measurement field is less than one-half the size of the interior square and is accurately positioned not to extend beyond the boundary of the interior square. The photometer should be checked for light scattering or lens flare effects which allow light from the surround to enter the photosensor. A black card with aperture equal to the measurement field (one-half the size of the interior black square) may be used to shield the photometer from the white exterior square while making measurements in the interior black square.

Analysis: Compute the percent halation for each test target configuration. Percent halation is defined as:

$$\% \text{ Halation} = L_{black} / (L_{white} - L_{black}) \times 100$$

Where, L_{black} = measured luminance of interior square displayed at L_{black} using input count level zero,

L_{white} = measured luminance of interior square displayed at L_{white} using input count level determined to produce a full screen luminance of 75% L_{max} .

Data: Table II.4-1 contains measured values of L_{black}, L_{white} and percentage halation.

Table II.4-1 Halation for 1600 x 1200 Addressability

	Reported Values	Range for 4% uncertainty
Lblack	0.50 fL ± 4%	0.48 fL to 0.52 fL
Lwhite	26.1 fL ± 4%	25.1 fL to 27.2 fL
Halation	1.92% ± 0.2%	1.77 % to 2.08 %

II.5. Color Temperature

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 5.4, page 22.

The CCT of the measured white point lies within the boundaries accepted by IEC.

Objective: Insure measured screen white of a color monitor has a correlated color temperature (CCT) between 6500K and 9300K.

Equipment: Colorimeter

Procedure: Command screen to Lmax. Measure u'v' chromaticity coordinates (CIE 1976).

Data: Coordinates of screen white should be within 0.01 Δu'v' of the corresponding CIE daylight, which is defined as follows: If the measured screen white has a CCT between 6500 and 9300 K, the corresponding daylight has the same CCT as the screen white. If the measured CCT is greater than 9300 K, the corresponding daylight is D93. If the measured CCT is less than 6500 K, the corresponding daylight is D65. The following equations were used to compute Δu'v' values listed in table II.5.1:

1. Compute the correlated color temperature (CCT) associated with (x,y) by the VESA/McCamy formula: CCT = 437 n^3 + 3601 n^2 + 6831 n + 5517, where n = (x-0.3320)/(0.1858 - y). [This is on p. 227 of the FPDM standard]

2. If CCT < 6500, replace CCT by 6500. If CCT > 9300, replace CCT by 9300.

4. Use formulas 5(3.3.4) and 6(3.3.4) in Wyszecki and Stiles (pp.145-146 second edition) to compute the point (xd,yd) associated with CCT.
   - First, define u = 1000/CCT.
   - If CCT < 7000, then xd = -4.6070 u^3 + 2.9678 u^2 + 0.09911 u +
   - 0.244063.
   - If CCT > 7000, then xd = -2.0064 u^3 + 1.9018 u^2 + 0.24748 u +
   - 0.237040.
   - In either case, yd = -3.000 xd^2 + 2.870 xd -0.275.

5. Convert (x,y) and (xd,yd) to u'v' coordinates:
   - (u',v') = (4x,9y)/(3 + 12y - 2x)
   - (u'd,v'd) = (4xd,9yd)/(3 + 12yd - 2xd)

6. Evaluate delta-u'v' between (u,v) and (ud,vd):
   - delta-u'v' = sqrt[(u' - u'd)^2 + (v' - v'd)^2].

7. If delta-u'v' is greater than 0.01, display fails the test. Otherwise it passes the test.

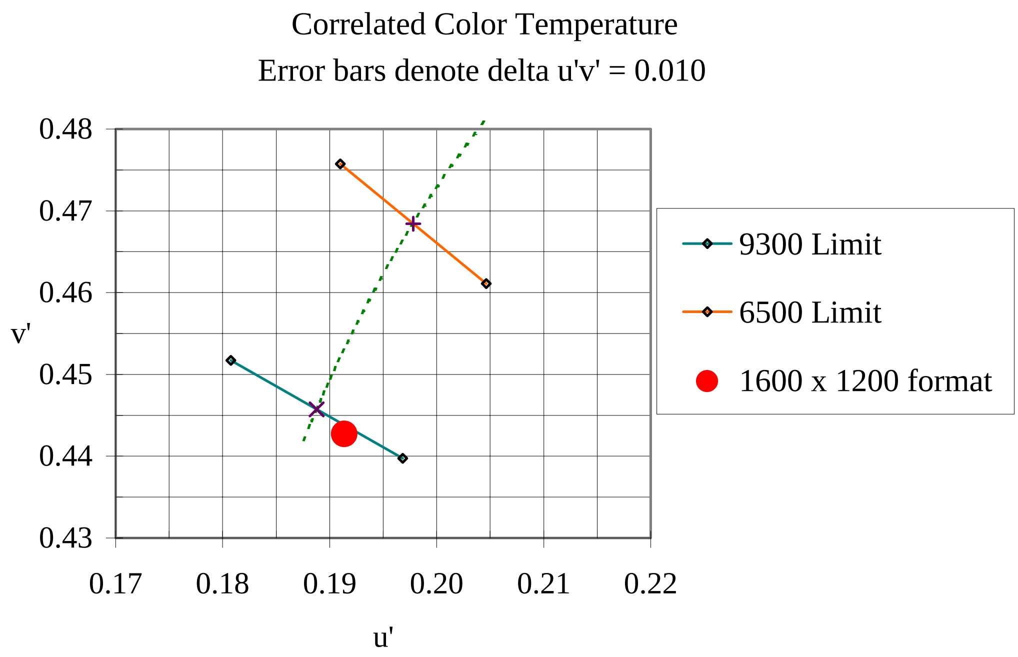


Figure II.5-1 *CCTs of measured whitepoints are within the boundaries required by IEC.*

Table II.5-1 Δu’v’ distances between measured whitepoints and CIE coordinate values from D_{65} to D_{93}.

	1600 x 1200
CIE x	0.284
CIE y	0.292
CIE u'	0.191
CIE v'	0.443
CCT	9380 K
delta u'v'	0.004

II.6. Bit Depth

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.

Positive increases in luminance were measured for each of the 256 input levels for 8 bits of gray scale. Neither black level clipping nor white level saturation was observed.

Objective: Measure the number of bits of data that can be displayed as a function of the DAC and display software.

Equipment: Photometer

Test targets: Targets are n four inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels.

Procedure: Measure patch center for all patches with Lmin and Lmax as defined previously. Count number of monotonically increasing luminance levels. Use the NEMA/DICOM model to define discriminable luminance differences. For color displays, measure white values.

Data: Define bit depth by $\log_2$ (number of discrete luminance levels)

The number of bits of data that can be displayed as a function of the input signal voltage level were verified through measurements of the luminance of white test targets displayed using a Quantum Data 8701 test pattern generator and a Minolta CA-100 colorimeter. Targets are n four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels. The NEMA/DICOM model was used to define discriminable luminance differences in JNDs.

Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2.

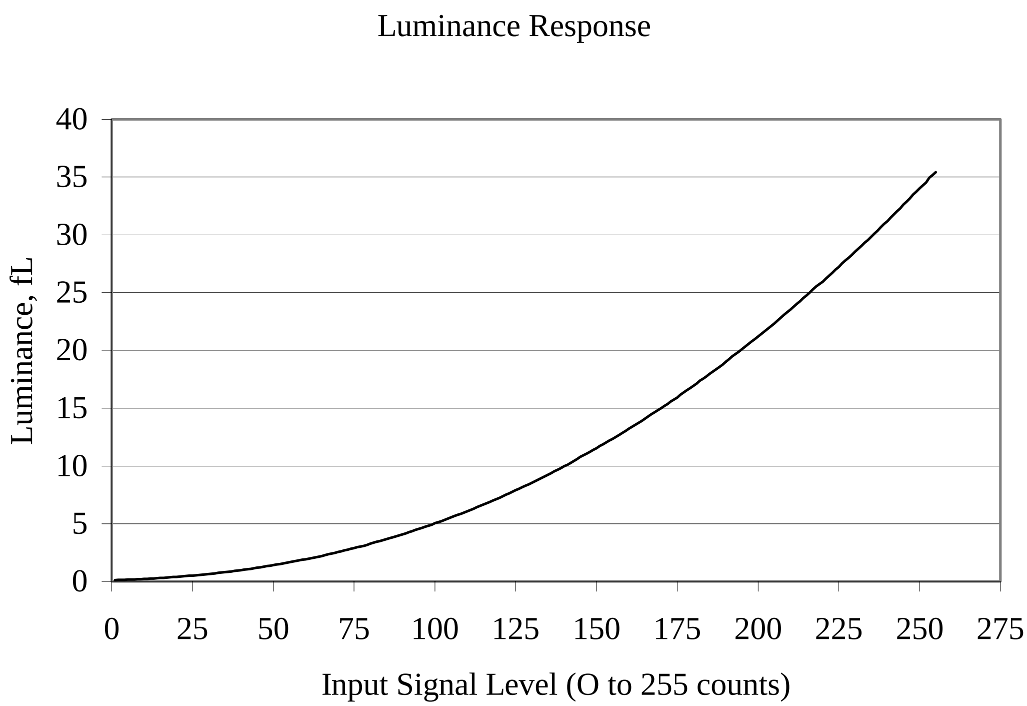


Figure II.6-1. System Tonal Transfer at center screen as a function of input counts.

Table II.6-1. System Tonal Transfer at center screen as a function of input counts. Target levels 000 to 127.

Back Ground	Target	L, fL	Diff, fL	Diff, JND	Back Ground	Target	L, fL	Diff, fL	Diff, JND
38	0	0.111	0.00	0	61	64	2.135	0.05	2
39	1	0.118	0.01	2	61	65	2.196	0.06	2
39	2	0.127	0.01	2	62	66	2.282	0.09	3
39	3	0.136	0.01	2	62	67	2.347	0.06	3
40	4	0.144	0.01	2	62	68	2.408	0.06	2
40	5	0.153	0.01	2	63	69	2.473	0.06	2
41	6	0.163	0.01	2	63	70	2.542	0.07	2
41	7	0.176	0.01	2	63	71	2.616	0.07	3
41	8	0.189	0.01	3	64	72	2.677	0.06	2
42	9	0.203	0.01	2	64	73	2.734	0.06	2
42	10	0.216	0.01	2	64	74	2.816	0.08	2
42	11	0.23	0.01	3	65	75	2.887	0.07	2
43	12	0.247	0.02	2	65	76	2.958	0.07	3
43	13	0.261	0.01	2	65	77	3.035	0.08	2
43	14	0.278	0.02	3	66	78	3.082	0.05	1
44	15	0.295	0.02	2	66	79	3.158	0.08	2
44	16	0.318	0.02	4	66	80	3.269	0.11	3
44	17	0.336	0.02	2	67	81	3.348	0.08	3
45	18	0.357	0.02	3	67	82	3.429	0.08	2
45	19	0.376	0.02	2	67	83	3.496	0.07	2
45	20	0.397	0.02	2	68	84	3.574	0.08	2
46	21	0.418	0.02	3	68	85	3.669	0.10	2
46	22	0.439	0.02	2	69	86	3.756	0.09	2
46	23	0.465	0.03	3	69	87	3.841	0.09	2
47	24	0.488	0.02	2	69	88	3.911	0.07	2
47	25	0.512	0.02	3	70	89	4.008	0.10	2
48	26	0.536	0.02	2	70	90	4.069	0.06	2
48	27	0.563	0.03	3	70	91	4.156	0.09	2
48	28	0.586	0.02	2	71	92	4.271	0.12	3
49	29	0.617	0.03	3	71	93	4.366	0.09	2
49	30	0.646	0.03	2	71	94	4.468	0.10	2
49	31	0.677	0.03	3	72	95	4.552	0.08	2
50	32	0.707	0.03	2	72	96	4.629	0.08	1
50	33	0.738	0.03	3	72	97	4.749	0.12	3
50	34	0.769	0.03	2	73	98	4.839	0.09	2
51	35	0.805	0.04	3	73	99	4.921	0.08	2
51	36	0.837	0.03	2	73	100	5.035	0.11	2
51	37	0.869	0.03	2	74	101	5.125	0.09	2
52	38	0.906	0.04	3	74	102	5.219	0.09	1
52	39	0.946	0.04	3	74	103	5.321	0.10	2
52	40	0.979	0.03	2	75	104	5.428	0.11	2
53	41	1.018	0.04	2	75	105	5.542	0.11	3
53	42	1.053	0.03	2	76	106	5.659	0.12	2
53	43	1.094	0.04	3	76	107	5.764	0.11	2
54	44	1.141	0.05	3	76	108	5.858	0.09	1
54	45	1.186	0.04	2	77	109	5.957	0.10	2
55	46	1.226	0.04	3	77	110	6.065	0.11	2
55	47	1.271	0.04	2	77	111	6.179	0.11	2
55	48	1.326	0.06	3	78	112	6.301	0.12	2
56	49	1.367	0.04	2	78	113	6.424	0.12	2
56	50	1.416	0.05	3	78	114	6.535	0.11	2
56	51	1.461	0.05	2	79	115	6.663	0.13	2
57	52	1.508	0.05	2	79	116	6.771	0.11	2
57	53	1.559	0.05	3	79	117	6.891	0.12	2
57	54	1.612	0.05	2	80	118	7.019	0.13	2
58	55	1.662	0.05	2	80	119	7.142	0.12	1
58	56	1.707	0.05	2	80	120	7.244	0.10	2
58	57	1.766	0.06	3	81	121	7.387	0.14	2
59	58	1.821	0.05	2	81	122	7.518	0.13	2
59	59	1.878	0.06	3	81	123	7.632	0.11	2
59	60	1.911	0.03	1	82	124	7.762	0.13	2
60	61	1.972	0.06	3	82	125	7.892	0.13	1
60	62	2.032	0.06	2	83	126	8.023	0.13	2
60	63	2.084	0.05	2	83	127	8.152	0.13	2

Table II.6-2. System Tonal Transfer at center screen as a function of input counts
Target levels 128 to 255.

Back ground	Target	L, fL	Diff, fL	Diff, JND
83	128	8.285	0.13	2
84	129	8.414	0.13	1
84	130	8.546	0.13	2
84	131	8.689	0.14	2
85	132	8.829	0.14	2
85	133	8.968	0.14	2
85	134	9.112	0.14	1
86	135	9.249	0.14	2
86	136	9.386	0.14	2
86	137	9.535	0.15	2
87	138	9.684	0.15	1
87	139	9.832	0.15	2
87	140	9.976	0.14	2
88	141	10.11	0.13	1
88	142	10.26	0.15	2
88	143	10.42	0.16	2
89	144	10.61	0.19	2
89	145	10.78	0.17	2
90	146	10.92	0.14	1
90	147	11.08	0.16	2
90	148	11.23	0.15	2
91	149	11.39	0.16	1
91	150	11.55	0.16	2
91	151	11.73	0.18	2
92	152	11.87	0.14	1
92	153	12.03	0.16	2
92	154	12.21	0.18	2
93	155	12.35	0.14	1
93	156	12.52	0.17	2
93	157	12.68	0.16	1
94	158	12.87	0.19	2
94	159	13.04	0.17	1
94	160	13.22	0.18	2
95	161	13.39	0.17	2
95	162	13.57	0.18	1
95	163	13.74	0.17	2
96	164	13.91	0.17	1
96	165	14.09	0.18	2
97	166	14.28	0.19	1
97	167	14.47	0.19	2
97	168	14.65	0.18	2
98	169	14.84	0.19	1
98	170	15.01	0.17	2
98	171	15.2	0.19	1
99	172	15.37	0.17	2
99	173	15.58	0.21	1
99	174	15.75	0.17	2
100	175	15.92	0.17	1
100	176	16.16	0.24	2
100	177	16.37	0.21	1
101	178	16.55	0.18	2
101	179	16.76	0.21	1
101	180	16.95	0.19	2
102	181	17.15	0.20	1
102	182	17.38	0.23	2
102	183	17.56	0.18	1
103	184	17.75	0.19	2
103	185	17.97	0.22	1
104	186	18.18	0.21	2
104	187	18.35	0.17	1
104	188	18.56	0.21	1
105	189	18.79	0.23	2
105	190	19.02	0.23	1
105	191	19.24	0.22	2

Back ground	Target	L, fL	Diff, fL	Diff, JND
106	192	19.46	0.22	1
106	193	19.67	0.21	2
106	194	19.85	0.18	1
107	195	20.09	0.24	1
107	196	20.31	0.22	2
107	197	20.53	0.22	1
108	198	20.76	0.23	1
108	199	20.97	0.21	2
108	200	21.18	0.21	1
109	201	21.41	0.23	1
109	202	21.64	0.23	2
109	203	21.87	0.23	1
110	204	22.08	0.21	1
110	205	22.31	0.23	2
111	206	22.54	0.23	1
111	207	22.81	0.27	2
111	208	23.06	0.25	1
112	209	23.29	0.23	1
112	210	23.52	0.23	2
112	211	23.78	0.26	1
113	212	24.01	0.23	1
113	213	24.25	0.24	2
113	214	24.51	0.26	1
114	215	24.75	0.24	1
114	216	24.99	0.24	2
114	217	25.26	0.27	1
115	218	25.51	0.25	1
115	219	25.73	0.22	1
115	220	25.94	0.21	2
116	221	26.22	0.28	1
116	222	26.46	0.24	1
116	223	26.71	0.25	1
117	224	26.99	0.28	2
117	225	27.22	0.23	1
118	226	27.51	0.29	1
118	227	27.76	0.25	2
118	228	27.99	0.23	1
119	229	28.24	0.25	1
119	230	28.53	0.29	1
119	231	28.79	0.26	1
120	232	29.03	0.24	2
120	233	29.31	0.28	1
120	234	29.54	0.23	1
121	235	29.83	0.29	1
121	236	30.09	0.26	1
121	237	30.35	0.26	2
122	238	30.65	0.30	1
122	239	30.93	0.28	1
122	240	31.17	0.24	1
123	241	31.49	0.32	1
123	242	31.76	0.27	2
123	243	32.05	0.29	1
124	244	32.28	0.23	1
124	245	32.62	0.34	1
125	246	32.86	0.24	1
125	247	33.16	0.30	1
125	248	33.48	0.32	2
126	249	33.74	0.26	1
126	250	34.03	0.29	1
126	251	34.29	0.26	1
127	252	34.53	0.24	1
127	253	34.94	0.41	2
127	254	35.17	0.23	1
128	255	35.43	0.26	1

II.8. Luminance Step Response

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.8, p 7.

No video artifacts were observed.

Objective: Determine the presence of artifacts caused by undershoot or overshoot.

Equipment: Test targets, SMPTE Test Pattern RP-133-1991, 2-D CCD array

Procedure: Display a center box 15% of screen size at input count levels corresponding to 25%, 50%, 75%, and 100% of Lmax with a surround of count level 0. Repeat using SMPTE Test pattern

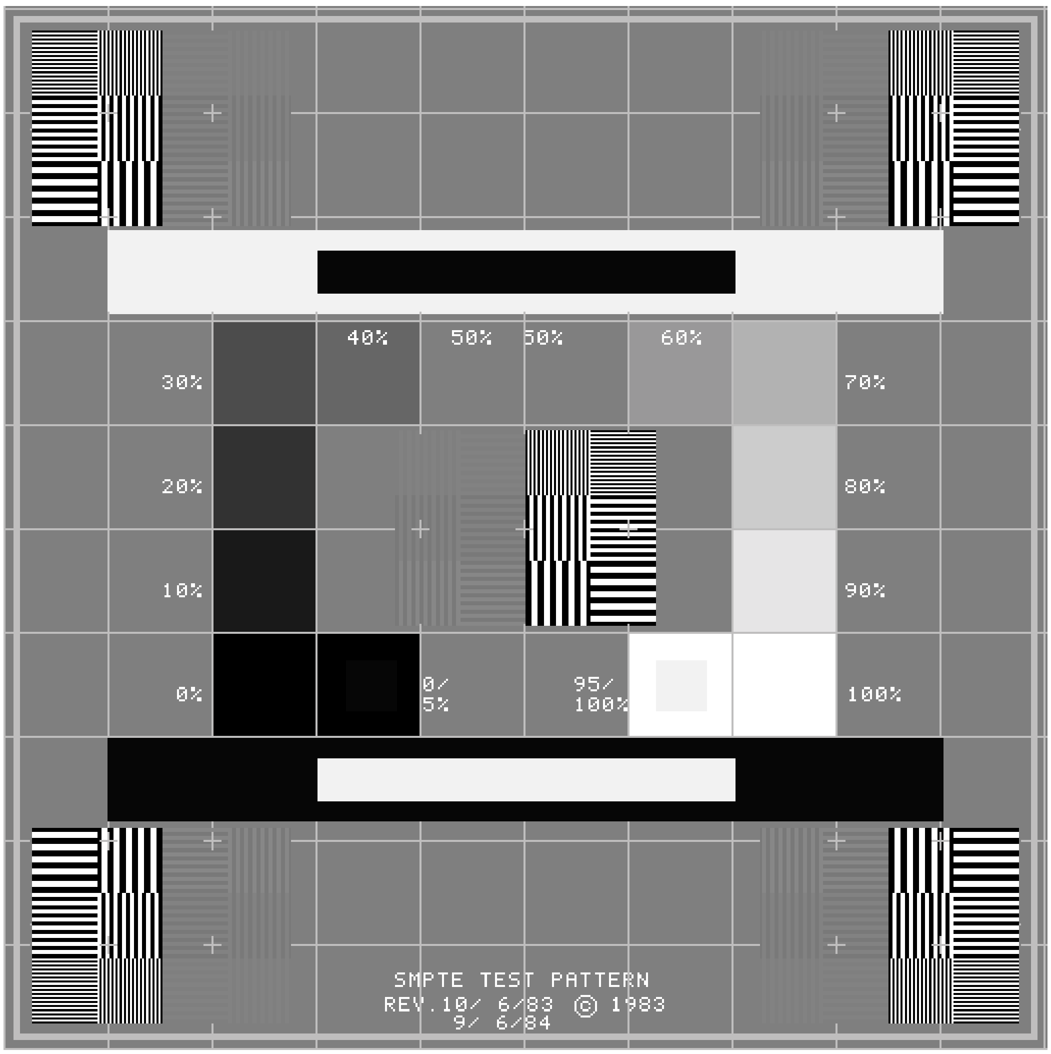


Figure II.8-1. SMPTE Test Pattern.

Data: Define pass by absence of noticeable ringing, undershoot, overshoot, or streaking.

The test pattern shown in Figure II.8-1 was used in the visual evaluation of the monitor. This test pattern is defined in SMPTE Recommended Practice RP-133-1986 published by the Society of Motion Picture and Television Engineers (SMPTE) for medical imaging applications. Referring to the large white-in-black and black-in-white horizontal bars contained in the test pattern, RP133-1986, paragraph 2.7 states " These areas of maximum contrast facilitate detection of mid-band streaking (poor low-frequency response), video amplifier ringing or overshoot, deflection interference, and halo." None of these artifacts was observed in the SONY GDM F500R monitor, signifying good electrical performance of the video circuits.

II.9. Addressability

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1, page 67.

This monitor properly displayed all addressed pixels for the following tested format (HxV):
1600 x 1200 x 72 Hz, 1024 x 1024 x 112 Hz.

Objective: Define the number of addressable pixels in the horizontal and vertical dimension; confirm that stated number of pixels is displayed.

Equipment: Programmable video signal generator.
Test pattern with pixels lit on first and last addressable rows and columns and on two diagonal lines beginning at upper left and lower right; H & V grill patterns 1-on/1-off.

Procedure: The number of addressed pixels were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible. All perimeter lines were confirmed to be visible, with no irregular jaggies on diagonals and, for monochrome monitors, no strongly visible moiré on grilles.

Data: If tests passed, number of pixels in horizontal and vertical dimension. If test fails, addressability unknown.

Table II.9-1 Addressabilities Tested

Monoscopic Mode	Stereo Mode
1600 x 1200	1024 x 1024

II.10. Pixel Aspect Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.10, p 8.

Pixel aspect ratio is within 1.8%.

Objective: Characterize aspect ratio of pixels.

Equipment: Test target, measuring tape with at least 1/16th inch increments

Procedure: Display box of 400 x 400 pixels at input count corresponding to 50% Lmax and background of 0. Measure horizontal and vertical dimension.

Alternatively, divide number of addressable pixels by the total image size to obtain nominal pixel spacings in horizontal and vertical directions.

Data: Define pass if H= V± 6% for pixel density <100 ppi and ± 10% for pixel density > 100 ppi.

	Monoscopic Mode
Addressability (H x V)	**1600 x 1200**
H x V Image Size (inches) H x V Pixel Spacing (mils) H x V Pixel Aspect Ratio	15.038 x 11.486 9.40 x 9.57 H = V + 1.8%

II.11. Screen Size (Viewable Active Image)

Reference: VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998, Section 501-1.

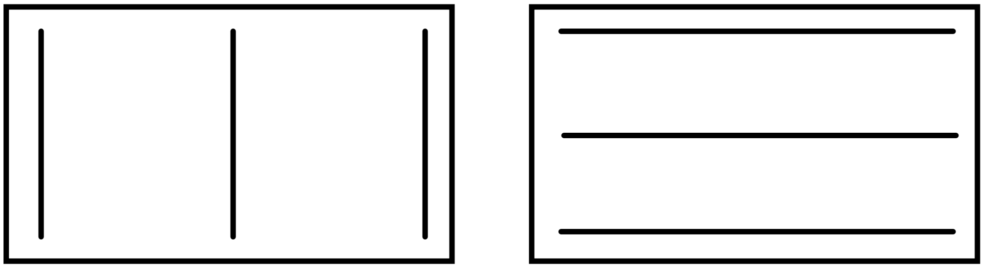
Image size as tested in monoscopic mode (1600 x 1200) was 18.923 inches in diagonal.

Objective: Measure beam position on the CRT display to quantify width and height of active image size visible by the user (excludes any overscanned portion of an image).

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.11-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be

positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.11-1 Three-line grille test patterns.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x,y coordinates of lines at the ends of the major and minor axes.

Data: Compute the image width defined as the average length of the horizontal lines along the top, bottom and major axis of the screen. Similarly, compute the image height defined as the average length of the vertical lines along the left side, right side, and minor axis of the screen. Compute the diagonal screen size as the square-root of the sum of the squares of the width and height.

Table II.11-1. Image Size

	Monoscopic Mode
Addressability (H x V)	**1600 x 1200**
H x V Image Size (inches) Diagonal Image Size (inches)	15.038 x 11.486 18.923

II.12. Contrast Modulation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 5.2, page 57.

Contrast modulation (Cm) for 1-on/1-off grille patterns displayed at 50% Lmax exceeded Cm = 40% in Zone A, and exceeded Cm = 37% in Zone B.

Objective: Quantify contrast modulation as a function of screen position.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Photometer with linearized response

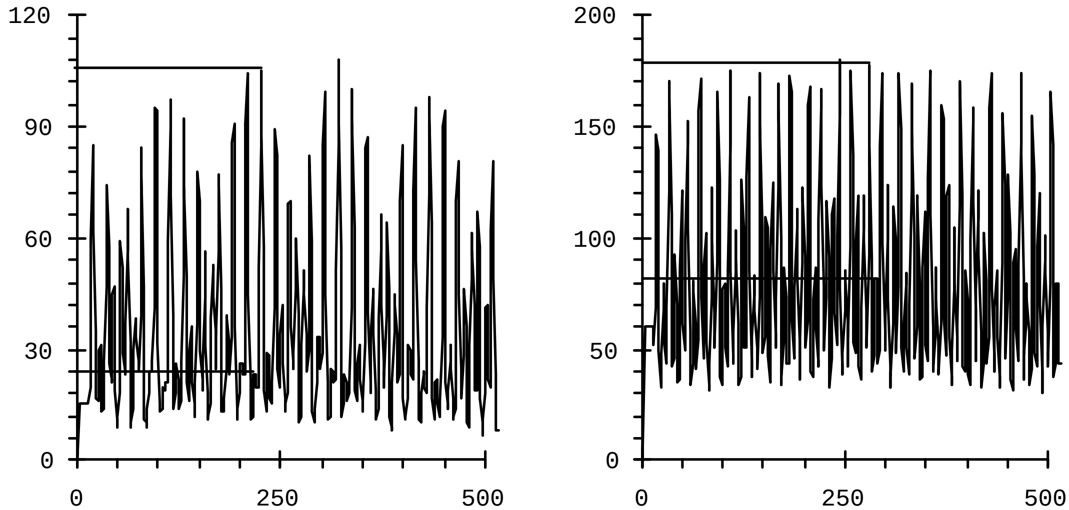
Procedure: The maximum video modulation frequency for each format (1600 x 1200) was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. Contrast modulation was measured in both horizontal and vertical directions at screen center and at eight peripheral screen positions. The measurements should be along the horizontal and vertical axes and along the diagonal from these axes. Use edge measurements no more than 10% of screen size in from border of active screen. The input signal level was set so that 1-line-on/1-line-off horizontal grille patterns produced a screen area-luminance of 25% of maximum level, Lmax.

Zone A is defined as a 24 degree subtended circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define Cm for Zone B (remaining area outside center circle). Determine Cm at eight points on circumference of circle by interpolating between center and display edge measurements to define Cm for Zone A. If measurements exceed the threshold, do not make any more measurements. If one or more measurements fail the threshold, make eight additional measurements at the edge (but wholly within) the defined circle.

Data: Values of vertical and horizontal Cm for Zone A and Zone B are given in Table II.12-1. The contrast modulation, Cm, is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation is equal to or greater than 43% in Zone A (7.6 inch), and is equal to or greater than 37% in Zone B

$$C_m = \frac{L_{peak} - L_{valley}}{L_{peak} + L_{valley}}$$

The sample contrast modulations shown in Figure II.12-1 for two different color CRTs are not fully realized because of the presence of moiré caused by aliasing between the image and the shadowmask. Because contrast modulation values are calculated for the maximum peak and minimum valley luminance levels as indicated in the sample data shown, they do not include the degrading effects of aliasing.



Monitor A
0.28mm dot pitch

Monitor B
0.26mm dot pitch

Figure II.12-1. *Contrast modulation for sample luminance profiles (1 pixel at input level corresponding to 50% Lmax, 1 pixel at level 0 = Lmin) for monitors exhibiting moiré due to aliasing.*

Table II.12-1. Contrast Modulation
Corrected for lens flare and Zone Interpolation

Zone A = 7.6-inch diameter circle for 24-degree subtended at 18-inch viewing distance

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	65%	57%			37%	66%			41%	62%
			59%	65%	43%	68%	50%	67%		
Major	73%	50%	64%	60%	55%	71%	59%	66%	62%	61%
			58%	59%	47%	68%	51%	65%		
Bottom	61%	42%			42%	66%			43%	55%

Zone A = 9.45-inch diameter circle for 40% area

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	65%	57%			37%	66%			41%	62%
			60%	64%	40%	67%	48%	66%		
Major	73%	50%	66%	58%	55%	71%	59%	65%	62%	61%
			58%	57%	45%	67%	50%	63%		
Bottom	61%	42%			42%	66%			43%	55%

II.13. Pixel Density

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.13, p 9.

Pixel density was 106 H x 104 V pixels per inch (ppi) as tested for the 1600 x 1200-line format.

Objective: Characterize density of image pixels

Equipment: Measuring tape with at least 1/16 inch increments

Procedure: Measure H&V dimension of active image window and divide by vertical and horizontal addressability

Data: Define horizontal and vertical pixel density in terms of pixels per inch

Table II.13-1. Pixel-Density

	Monoscopic Mode
H x V Addressability, Pixels	**1600 x 1200**
H x V Image Size, Inches H x V Pixel Density, ppi	15.038 x 11.486 106 x 104

II.14. Moiré

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.14, p 9.

Phosphor-to-pixel spacing ratios are less than for the 1600 x 1200 format (horizontal ratio =0.92). Compensation circuitry effectively reduces the visibility of moiré patterns when displaying 1-on/1-off vertical grille patterns.

Objective: Determine lack of moiré.

Equipment Loupe with scale graduated in 0.001 inch or equivalent

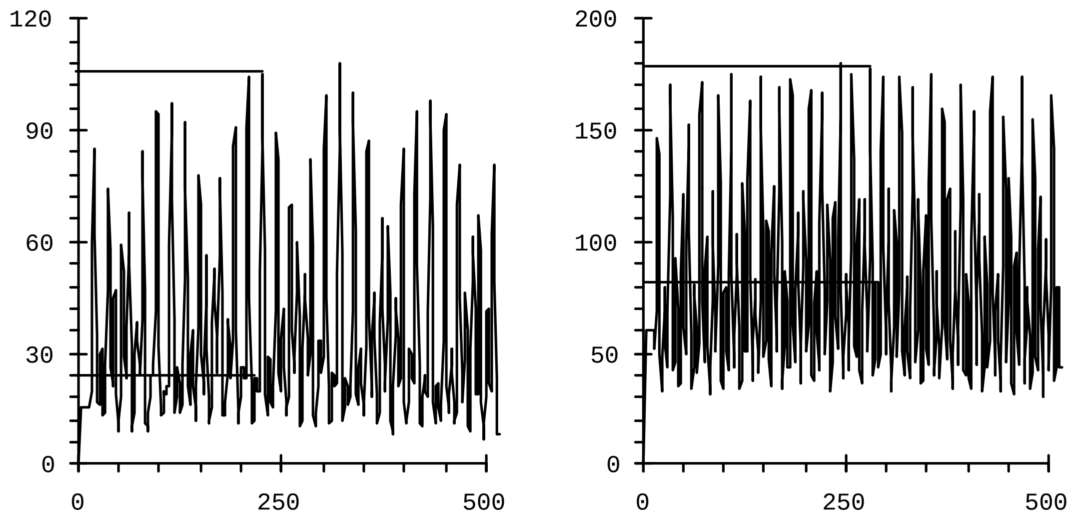
Procedure Measure phosphor pitch in vertical and horizontal dimension at screen center. For aperture grille screens, vertical pitch will be 0. Define pixel size by 1/pixel density.

Data: Define value of phosphor: pixel spacing. Value <1 passes, but <0.6 preferred.

Table II.14-1. Phosphor-to-Pixel-Spacing Ratios

	Monoscopic Mode
Addressability	**1600 x 1200**
Pixel Spacing (H x V)	9.40 x 9.57 mils
Phosphor Pitch (H)	0.22 mm
Phosphor-to-Pixel-Spacing	0.92

Discussion: Moiré occurs when the phosphor pitch is too large in comparison to the pixel size. Studies have shown that a phosphor pitch of about 0.6 pixels or less is required for adequate visibility of image information without interference from the phosphor structure.



Monitor A
0.28mm dot pitch

Monitor B
0.26mm dot pitch

Figure II.12-1. *Contrast modulation for sample luminance profiles (1pixel at level 50, 1 pixel at level 0) for monitors exhibiting moiré due to aliasing.*

In Figure II.12-1, Monitor A phosphor pitch is 0.90 pixels as compared with 0.84 pixels in Monitor B. Moiré is more visible in Monitor A, appearing as long stripes where contrast modulation has been degraded. In Monitor B, moiré is less visible, appearing as "fish-scales" where contrast modulation has been reduced. Even though the Monitor A exhibits a greater loss of contrast modulation from the presence of moiré on 1-on/1-off vertical grille patterns, there is little or no visual impact when aerial photographic images are displayed. NIDL experts in human vision and psychophysics were unable to discern presence of moiré on either monitor when grayscale imagery was displayed.

II.15. Straightness

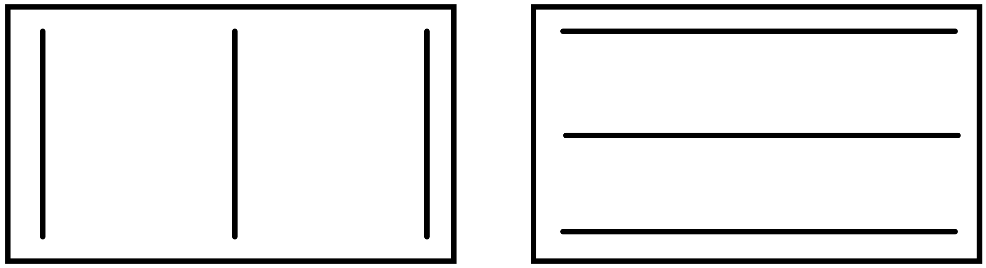
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

Waviness, a measure of straightness, did not exceed 0.12% of the total image height or width.

Objective: Measure beam position on the CRT display to quantify effects of waviness which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.15-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.15-1 Three-line grille test patterns.

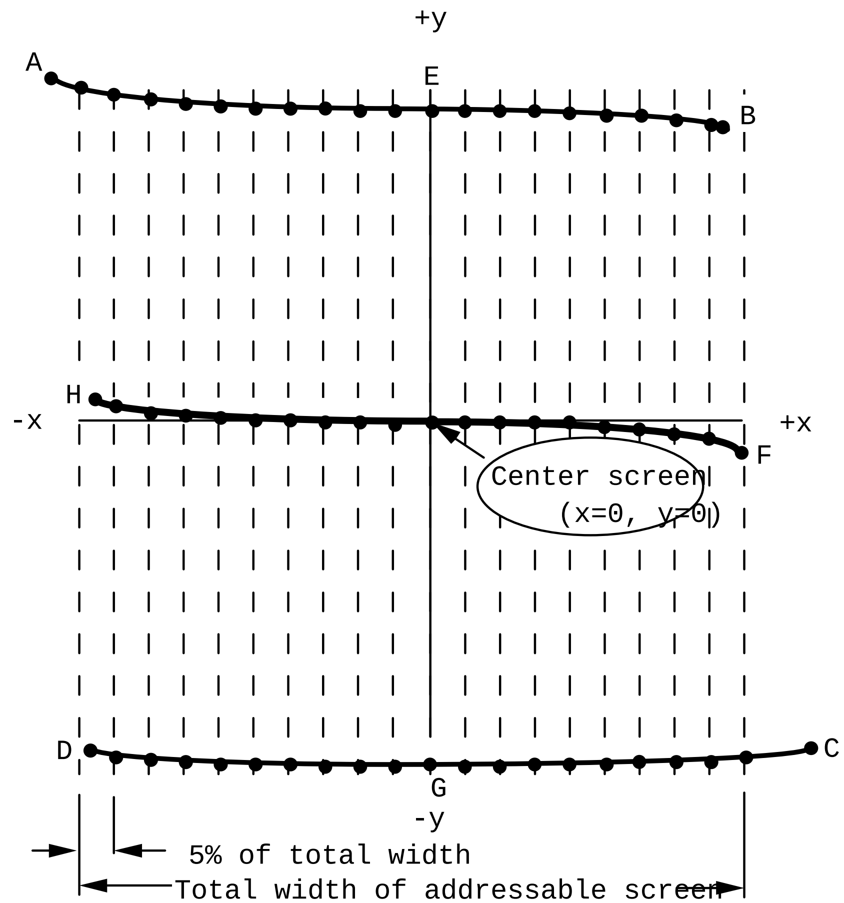


Figure II.15-2 Measurement locations for waviness along horizontal lines. Points A, B, C, D are extreme corner points of addressable screen. Points E, F, G, H are the endpoints of the axes.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x,y coordinates along the length of a nominally straight line. Measure x,y coordinates at 5% addressable screen intervals along the line. Position vertical lines in video to land at each of three (3) horizontal screen locations for determining waviness in the horizontal direction. Similarly, position horizontal lines in video to land at each of three (3) vertical screen locations for determining waviness in the vertical direction.

Data: Tabulate x,y positions at 5% addressable screen increments along nominally straight lines at top and bottom, major and minor axes, and left and right sides of the screen as shown in Table II.15-I. Figure II.15-3 shows the results in graphical form.

Table II.15-1. Straightness

Tabulated x,y positions at 5% addressable screen increments along nominally straight lines.

Top		Bottom		Major		Minor		Left Side		Right Side	
x	y	x	y	x	y	x	y	x	y	x	y
-7490	5733	-7513	-5751	-7485	-6	11	5729	-7485	5735	7556	5758
-7200	5733	-7200	-5756	-7200	-6	13	5400	-7483	5400	7551	5400
-6400	5733	-6400	-5757	-6400	-5	12	4800	-7483	4800	7548	4800
-5600	5732	-5600	-5756	-5600	-5	10	4200	-7483	4200	7548	4200
-4800	5731	-4800	-5754	-4800	-5	8	3600	-7483	3600	7547	3600
-4000	5731	-4000	-5753	-4000	-5	5	3000	-7483	3000	7547	3000
-3200	5730	-3200	-5752	-3200	-4	3	2400	-7483	2400	7547	2400
-2400	5730	-2400	-5750	-2400	-4	2	1800	-7484	1800	7546	1800
-1600	5729	-1600	-5748	-1600	-3	1	1200	-7487	1200	7544	1200
-800	5729	-800	-5746	-800	-2	1	600	-7489	600	7544	600
0	5729	0	-5743	0	0	0	0	-7490	0	7544	0
800	5731	800	-5741	800	0	-1	-600	-7493	-600	7543	-600
1600	5733	1600	-5738	1600	0	-3	-1200	-7496	-1200	7542	-1200
2400	5735	2400	-5736	2400	0	-4	-1800	-7497	-1800	7540	-1800
3200	5738	3200	-5734	3200	1	-4	-2400	-7497	-2400	7537	-2400
4000	5741	4000	-5732	4000	1	-5	-3000	-7497	-3000	7536	-3000
4800	5743	4800	-5731	4800	1	-6	-3600	-7499	-3600	7537	-3600
5600	5746	5600	-5733	5600	2	-7	-4200	-7502	-4200	7539	-4200
6400	5750	6400	-5735	6400	3	-8	-4800	-7506	-4800	7540	-4800
7200	5755	7200	-5735	7200	4	-9	-5400	-7510	-5400	7538	-5400
7552	5758	7530	-5734	7545	6	-11	-5746	-7512	-5754	7533	-5736

1600 x 1200

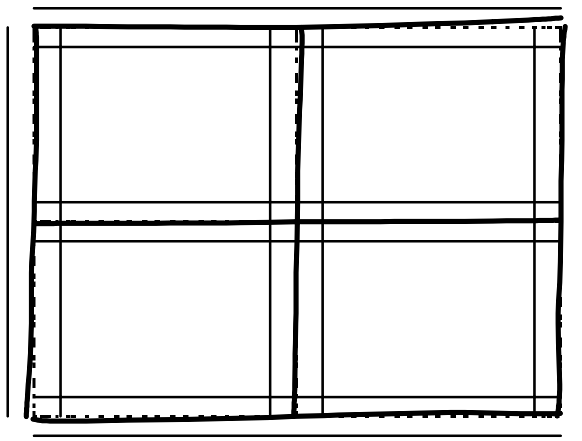


Figure II.15-3 Waviness of Sony GDM F500R Color monitor in 1600 x 1200 mode. Departures from straight lines are exaggerated on a 10X scale. Error bars are +/- 0.5% of total screen size.

II.16. Refresh Rate

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.16, p 9.

Vertical refresh rate for 1600 x 1200 format was set to 72 Hz. Vertical refresh rate for the 1024 x 1024 stereo format was set to112 Hz, limited by the monitor.

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible.

Data: Report refresh rates in Hz.

Table II.16-1 Refresh Rates as Tested

	Monoscopic Mode	**Stereo Mode**
Addressability	**1600 x 1200**	**1024 x 1024**
Vertical Scan	72 Hz	112 Hz
Horizontal Scan	90 kHz	120 kHz

II.17. Extinction Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio averaged 13.3 to 1 (13.3 left,13.2 right) at screen center. Luminance of white varied by up to 7.4% across the screen. Chromaticity variations of white were less than 0.006 delta u'v' units.

Objective: Measure stereo extinction ratio

Equipment: Two “stereo” pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially-available Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient). Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L(left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

Stereo extinction ratio is average of left and right ratios defined above.

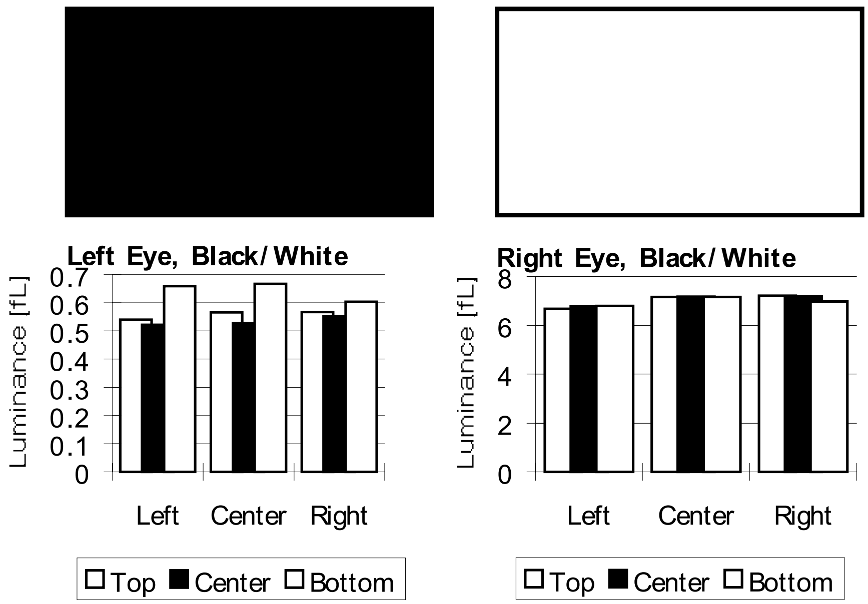


Fig.II.17-1. Spatial Uniformity of luminance in stereo mode when displaying black to the left eye while displaying white to the right eye.

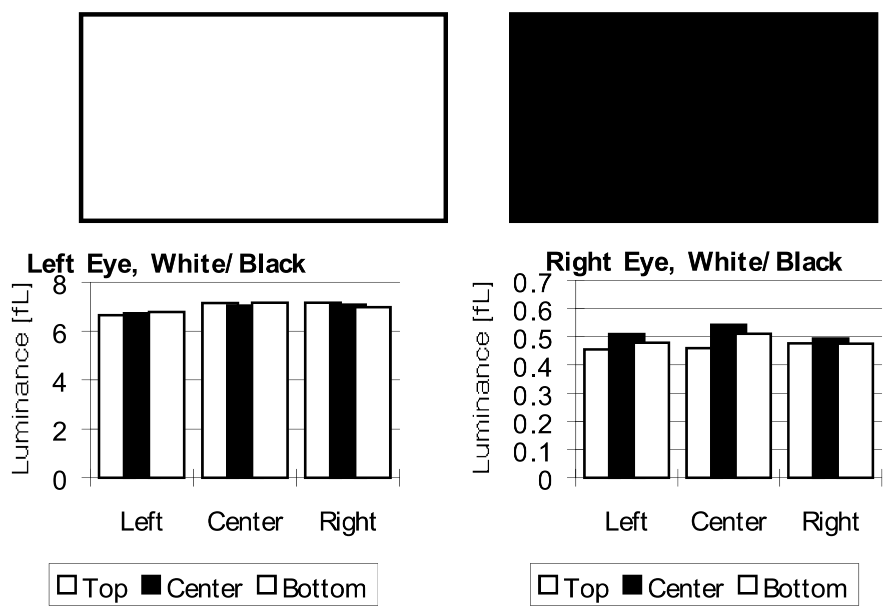


Fig.II.17-2. Spatial Uniformity of luminance in stereo mode when displaying white to the left eye while displaying black to the right eye.

Fig.II.17-3. Spatial Uniformity of extinction ratio in stereo mode.

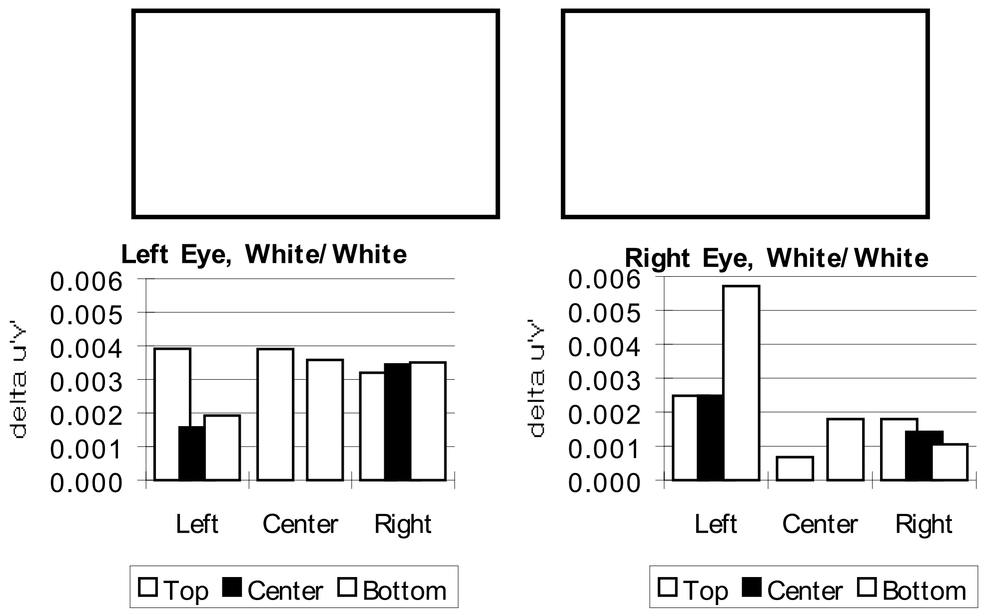


Fig.II.17-4 Spatial Uniformity of chromaticity of white in stereo mode.

II.18. Linearity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.2, page 73.

The maximum nonlinearity of the scan was 1.32% of full screen.

Objective: Measure the relation between the actual position of a pixel on the screen and the commanded position to quantify effects of raster nonlinearity. Nonlinearity of scan degrades the preservation of scale in images across the display.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use grille patterns of single-pixel horizontal lines and single-pixel vertical lines displayed at 100% L_{max}. Lines are equally spaced in addressable pixels. Spacing must be constant and equal to approximately 5% screen width and height to the nearest addressable pixel as shown in Figure II.18-1.

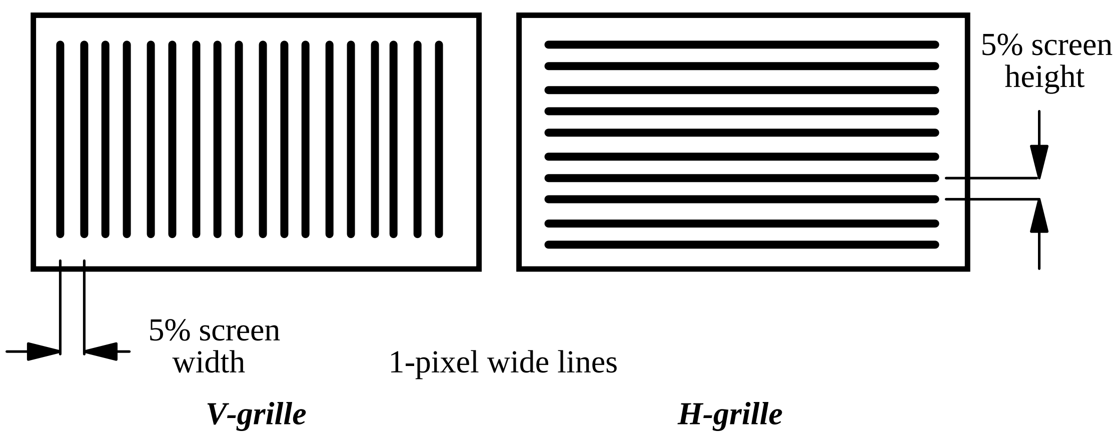


Figure II.18-1. *Grille patterns for measuring linearity*

Procedure: The linearity of the raster scan is determined by measuring the positions of lines on the screen. Vertical lines are measured for the horizontal scan, and horizontal lines for the vertical scan. Lines are commanded to 100% Lmax and are equally spaced in the time domain by pixel indexing on the video test pattern. Use optic module to locate center of line profiles in conjunction with x,y-translation stage to measure screen x,y coordinates of points where video pattern vertical lines intersect horizontal centerline of screen and where horizontal lines intersect vertical centerline of the CRT screen as shown in Figure II.18-2.

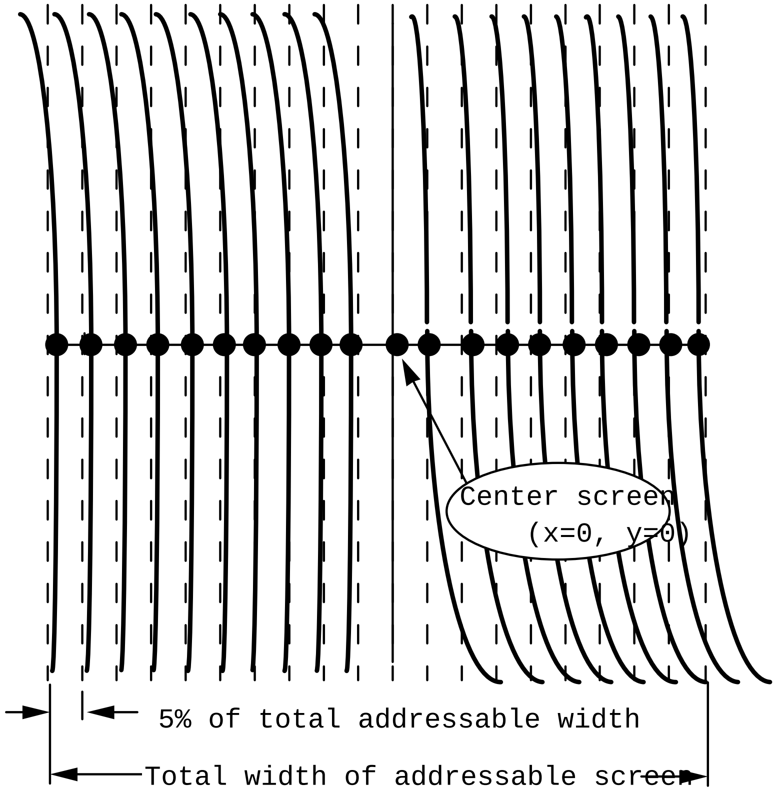


Figure II.18-2. *Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.*

Data: Tabulate x,y positions of equally spaced lines (nominally 5% addressable screen apart) along major (horizontal centerline) and minor (vertical centerline) axes of the raster. If both scans were truly linear, the differences in the positions of adjacent lines would be a constant. The departures of these differences from constancy impacts the absolute position of each pixel on the screen and is, then, the nonlinearity. The degree of nonlinearity may be different between left and right and between top and bottom. The maximum horizontal and vertical nonlinearities (referred to full screen size) are listed in table II.18-1. The complete measured data are listed in table II.18-2 and shown graphically in Figure II.18-3.

Table II.18-1. Maximum Horizontal and Vertical Nonlinearities

Format	Left Side	Right Side	Top	Bottom
1600 x 1200	0.74%	1.32%	0.13%	0.12%

Table II.18-2. Horizontal and Vertical Nonlinearities Data

Vertical Lines x-Position (mils)		Horizontal lines y-Position (mils)	
Left Side	Right Side	Top	Bottom
-7512	7604	5628	-5635
-6776	6824	5052	-5077
-6023	6043	4491	-4515
-5262	5262	3932	-3954
-4495	4486	3372	-3389
-3731	3721	2809	-2824
-2974	2967	2248	-2259
-2224	2218	1684	-1692
-1479	1478	1122	-1127
-742	739	562	-564
0	0	0	0

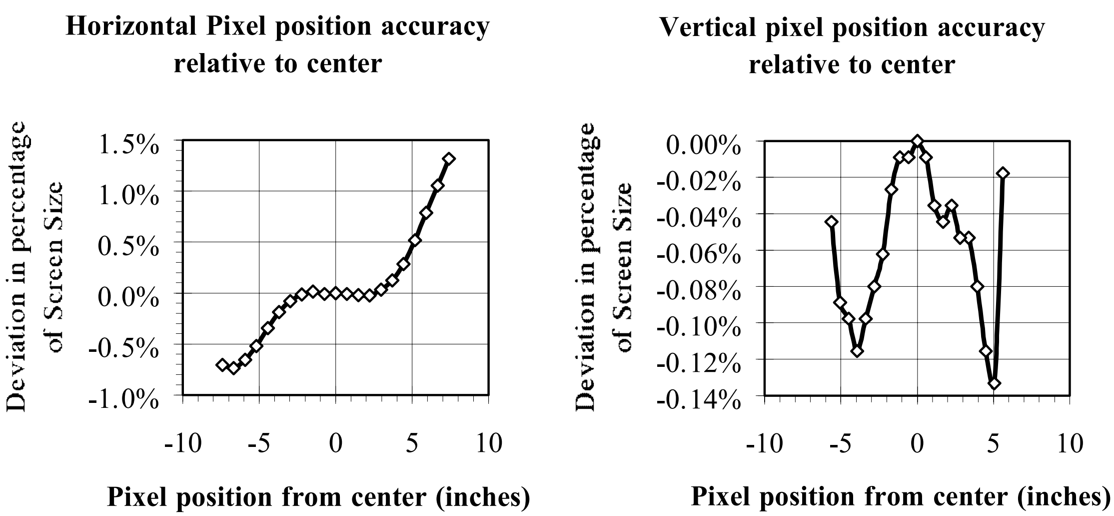


Fig. II.18-5 Horizontal and vertical linearity characteristics.

II.19. Jitter/Swim/Drift

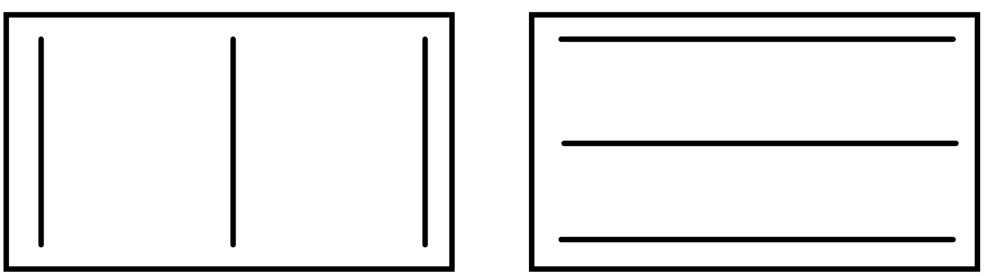
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 6.4, p80.

Maximum jitter and swim/drift was 2.76 mils and 3.17 mils, respectively.

Objective: Measure amplitude and frequency of variations in beam spot position of the CRT display. Quantify the effects of perceptible time varying raster distortions: jitter, swim, and drift. The perceptibility of changes in the position of an image depends upon the amplitude and frequency of the motions, which can be caused by imprecise control electronics or external magnetic fields.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.19-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



V-grille for measuring horizontal motion H-grille for measuring vertical motion

1-pixel wide lines

Three-line grille test patterns.
Figure II.19-1

Procedure: With the monitor set up for intended scanning rates, measure vertical and horizontal line jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration as displayed using grille video test patterns. Generate a histogram of raster variance with time. The measurement interval must be equal to a single field period.

Optionally, for multi-sync monitors measure jitter over the specified range of scanning rates. Some monitors running vertical scan rates other than AC line frequency may exhibit increased jitter.

Measure and report instrumentation motion by viewing Ronchi ruling or illuminated razor edge mounted to the top of the display. It may be necessary to mount both the optics and the monitor on a vibration-damped surface to reduce vibrations.

Data: Tabulate motion as a function of time in x-direction at top-left corner screen location. Repeat for variance in y-direction. Tabulate maximum motions (in mils) with display input count level corresponding to L_{max} for jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration. The data are presented in Table II.19-1. Both the monitor and the Microvision equipment sit on a vibration-damped aluminum-slab measurement bench. The motion of the test bench was a factor of 10 times smaller than the CRT raster motion.

Table II.19-1. Jitter/Swim/Drift

Time scales: Jitter 2 sec., Swim 10 sec., and Drift 60 sec.

1600 x 1200 x 72 Hz

Signal Generator			**Quantum Data FOX 8701**	
Position			H-lines	V-lines
10D corner	Max Motions			
		Jitter	2.76	2.70
		Swim	3.15	2.87
		Drift	3.17	3.00

II.20 Warm-up Period

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.20, p. 10.

A 75-minute warm-up was necessary for luminance stability of Lmin = 0.06 fL +/- 10%.

Objective: Define warm-up period

Equipment: Photometer, test target (full screen 0 count)

Procedure: Turn monitor off for three-hour period. Turn monitor on and measure center of screen luminance (Lmin as defined in Dynamic range measurement) at 1-minute intervals for first five minutes and five-minute intervals thereafter. Discontinue when three successive measurements are ± 10% of Lmin.

Data: Pass if Lmin within ± 50% in 30 minutes and ±10% in 60 minutes.

The luminance of the screen (commanded to the minimum input level, 0 for Lmin) was monitored for 120 minutes after a cold start. Measurements were taken every minute. Figure II.20-1 shows the data for 1600 x 1200 format in graphical form. The luminance remains very stable after 49 minutes.

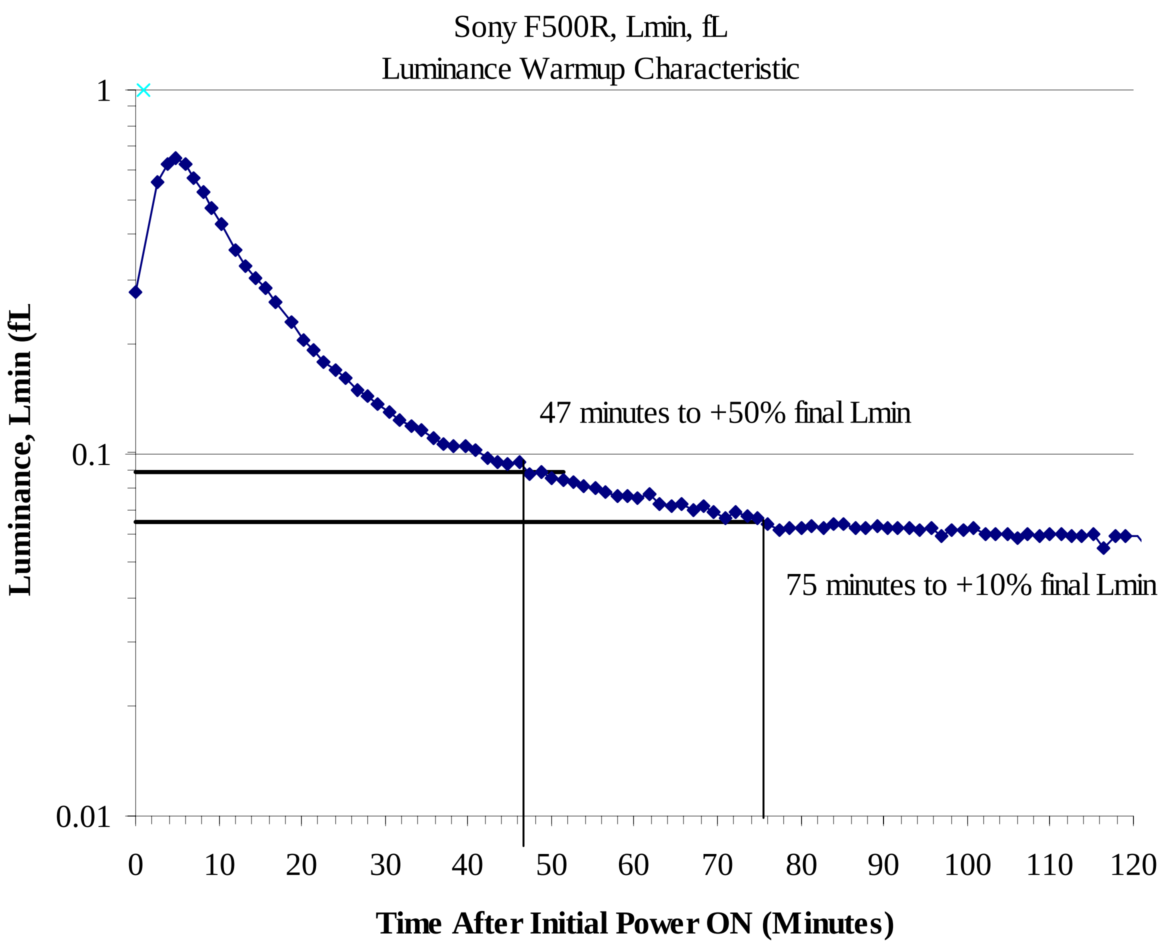


Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 0. (Note suppressed zero on luminance scale).